

Instrumentation and Monitoring of Mahawewa Landslide off Walapane in Central Hills of Sri Lanka

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Abstract: *As instability of the slope area at Mahawewa, Walapane has been identified as a major threat to the people since 1986, National Building Research Organization has started a project of monitoring and stabilization of the slope, cooperating with the Japan International Cooperation Agency in 2010. Main involvement of this study was to do the instrumentation and monitoring, mainly based on analysis of un-stabilization parameters of the area which measured using five instruments. That is horizontal movement at sub surface using Inclinator, fluctuation of ground water level using piezometers, characteristics of slip surfaces using strain gauges, movement of the surface using extensometers and rainfall using rain gauges. In addition to above drill log data of the site, visual information of cracks generated and springs available were also used. Finally, according to the results of analysis the unfavourable ground water level in slope area has been identified as the most critical factor of the landslide. According to that conclusion a suitable mitigation options for Mahawewa landslide were proposed.*

Keywords: *Landslides, Slip surfaces, Ground water level, Slope stabilization, Slope instrumentation*

1. INTRODUCTION

Landslide is a natural disaster which is caused significant impact to the economy of the country and creates number of problems such as, loss of human life, damage to the property and also damage to the natural environment. Landslide disaster has been reported with increasing frequency in recently at central hilly areas of Sri Lanka.

The instability of the rock slope at Mahawewa in Walapane was identified as a major risk to the safety of the people and property. That slope is located behind the Padiyapallalla town in Nuwara Eliya district in Central Hills of Sri Lanka. It belongs to Kumbalgamuwa GN division. The landscape in that area is very undulating with steep slopes. The initial signal of landslide was occurred in 1986, but in that time it was not highly concerned. Then again in 11th and 12th January 2007, 3 landslides were occurred in the area. Among them, one was activated by losing 18 lives and fully damaging 68 houses (<http://www.wsws.org/articles/2007/jan2007/sril-j31.shtml>).

Mahawewa area off Walapane has some importance in economical, agricultural and sociological aspects. If the landslide will be re-activated again, it is highly affecting to the Walapane Hanguranketha main road and also it can destroy the Keerthi Bandara School situated on the extreme down slope (<http://www.nb-ro.gov.lk/web>, NBRO home page, Mitigation of landslides). Therefore, after the 2007 tragedy, National Building Research Organization (NBRO) has started monitoring this landslide using instruments with some mitigating programme. This is the first time of doing such a total instrumentation procedure for monitoring the landslide, Sri Lanka. There are 5 types of instruments have been installed such as, Inclinator, Piezometer, Extensometers, Strain Gauges, and Rain Gauges (Fig 1).

Main involvement of ours on behalf of this study was to do the monitoring part by analysing the relationships of slope stabilizing parameters which were measured using those instruments. We used the relationships between following factors; rain fall of the area, fluctuation of the water table, movement of the surface ground (direction and extent of movement) and movement of the sub - surface ground (no of slip surfaces, possibility of their activation, depth from the surface to slip).

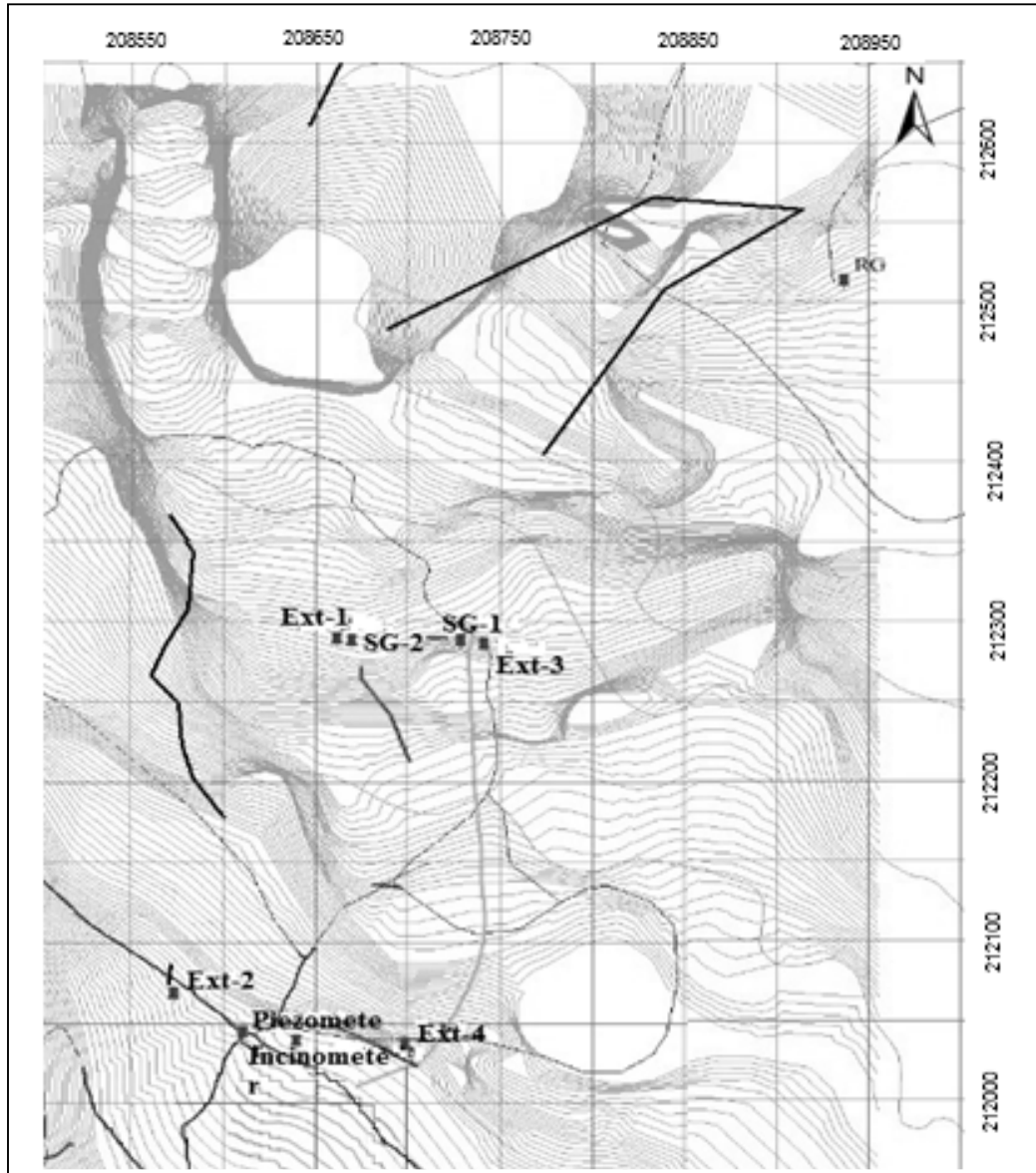


Figure 1 Instrumentation Location Map of Mahawewa Landslide

Ext - Extensometer
SG - Strain Gauge

2. METHODOLOGY

2.1 Data Collection and Field Survey

As the first step of our research, instrument installation processes and their particular locations were studied. Then one year data of all instruments were collected within suitable intervals. Data collection

was done by manually in Inclinator once a month while data has been automatically recorded in other instruments at each half an hour or one hour.

In addition to that, a Global Positioning System survey was conducted for the affected area to demarcate the boundary of the both past and current landslide, around the lake, along the cracks appeared and also at the location of instruments. Then using data of the map from NBRO, prepared a map of the area using Arc map 9.3 and 3D model of the slope using Auto Cad 2010.

2.2 Data Analysing for Surface movement

Generally, the first step of landslide monitoring consists of exploring the behaviour of surface material such as their direction of movement, extend of movement, rate of movement etc. In addition to that these initial evidences are directly affected on the installation of other instrument such as strain gauge and inclinometer. Therefore at the beginning, data extracted from the extensometer were studied for each day.

As it provides the relative movement between two points on the sliding body the readings were plotted against the time to realize the continuous movement during a considered time period. Then it was compared with the rainfall as it is the main driven force of all most all the landslides in Sri Lanka. Then regarding those graphs the particular sections which indicate rapid movements were further analysed. The errors identified were removed to clear visualization of the critical movement (Fig 2).

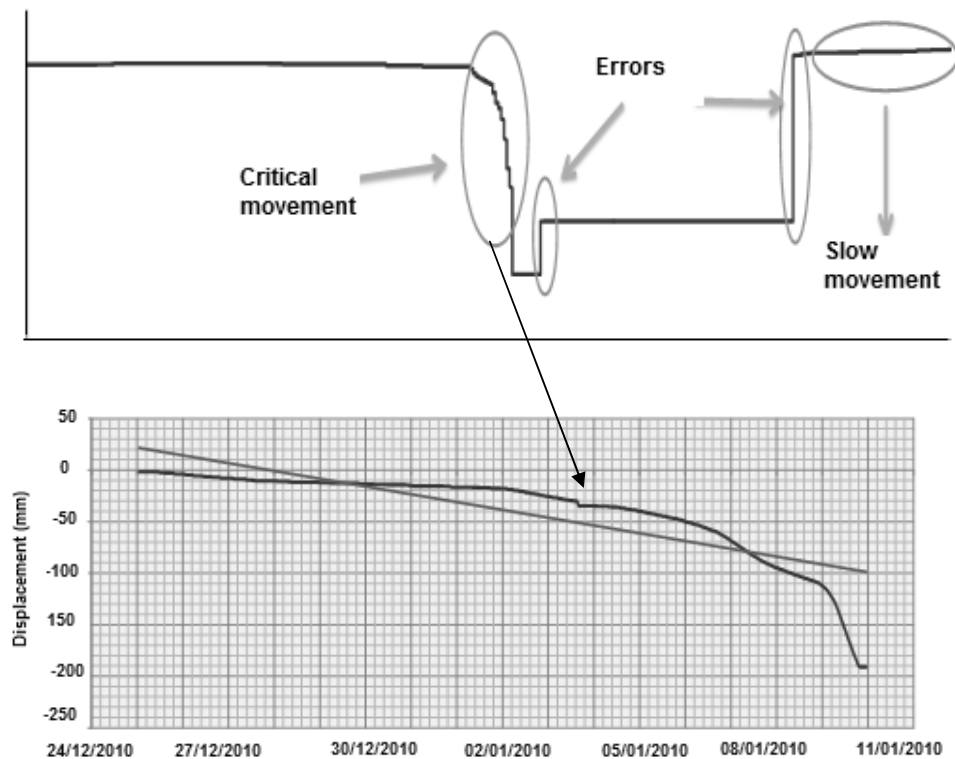


Figure 2 Analysing of surface displacement

In here with the help of a trend line, an equation was obtained in the format of " $y = Mx + C$ ". It gives a relationship between movement and time. Then the value received for the "M" indicates the rate of movement (mm per Day) while the sign mark (+,-) indicates the direction of movement. If a mines sign is received it indicates that the lower part is moving fast and vice versa.

2.3 Analysing of water level fluctuation

Water always tends to reduce the stability of the earth slopes. As an example when Cracks are filled with water, they create tension on slope. This tension force is a function of the height of water column in the crack. So ground water level decides the height of the water column in the tension crack.

Piezometer provides two values called **water level** and **groundwater level**. The fluctuation of groundwater level with the rainfall was plotted as follows (Fig 3).

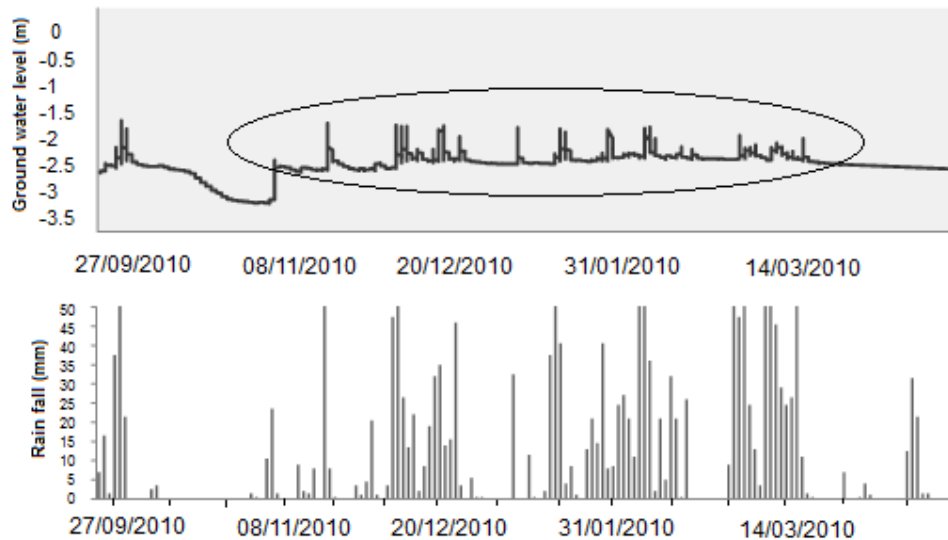


Figure 3 Groundwater level with the rain

As this diagram indicates groundwater level has been rapidly changed during the rainy season. It means that water get accumulated within the slope area which cause to increase the hydraulic pressure and reduce the factor of safety. To have a much accurate result upon ground water the data obtained from water gauge was also referred.

Then some crucial points which indicate rapid deviations of ground water level from the normal conditions were recognized and tried to find some reliable reasons which may cause those disturbances. By mean of closely analysing, the ground water level at the normal condition was determined. Then evaluate the amount of deviation from the normal value at a particular rainy condition. Then the water column height at a particular condition can be compared with the occurrence of the major slip surfaces.

2.4. Data Analysing for Sub Surface movement

2.4.1 Inclinator data

Data has been taken inserting a sensing unit (electronic probe) consists with wheels that track within the grooves of the inclinometer casing. These grooves are aligning to the direction of the slope sliding and it is named as "X" direction. The values visualized in readout unit also named as "X" values. Simultaneously it also gives the values regarding with perpendicular direction to the "X" and it is called the reading of "Y" direction. That data taken provide the information about inclination of the casing at various depths which implies the horizontal displacement of the ground with the depth. Normally two sets of readings were taken in each depth by running the instrument in the casing once and then repeating the procedure with the instrument turned 180°.

The instrument provides the angle of movement of the sliding slope, while after the data has been processed, the depth with respect to critical movement was recognized. On behalf of this, three graphs were plotted in the same X-Y plane for adjacent three months. Then check the comparison movements of the subsurface for each month.

2.4.2 Strain Gauge data

At the Mahawewa slope there are two strain gauges are installed and it provides the valuable result of depth to the potential slip surfaces. At first Strain Gauge data were plotted and identified some rapid changes (Fig 4). For having such a huge strain changing, there should be critical failures at the corresponding depth.

At the same time, the behaviour of these recognized failure surfaces has been daily monitored throughout the year to see whether the depth of failure surfaces has been changed. Because it changed with various kinds of external influences such as water percolation, slope consolidation, change in geological structures etc. And also for mitigations like soil nailing, these analysed data are very much crucial to decide the length of supported nails. The coordinates of major crack appeared at the top of the landslide were also used to correctly locate the identified Slip surfaces

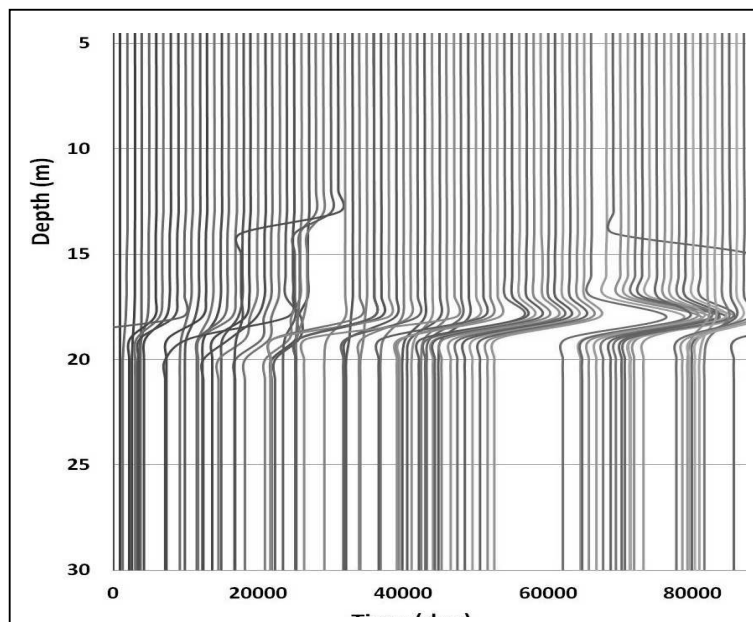


Figure 4 Identification of slip surfaces – Strain Gauge data

3. RESULTS AND DISCUSSION

3.1. Geomorphology of the area

The landscape of Mahawewa is very much undulating with steep slopes of 15° to 35° . There are two escarpments at the top area of the slope and near to that the whole area is filled with a colluvium deposit consisting of large size boulder (1 m to 5 m in diameter). There is a lake below the escarpment. It is now abandoned for some extent but still water can be appeared little below to the ground level even in dry season. Villagers in that area take the water through pipe lines from that abandoned lake. Newly appeared water spills could be identified at the middle area of the slope.

Newly formed cracks which are largely extended in the ground were identified at the whole area of the landslide while the major crack has been visualized at the top of the slope. And also walls and floor of the most houses are severely cracked.

3.2. Results of Extensometer (Ext)

Although there had been five extensometers installed before the very recent landslide occurred, by now it has been reduced to four. By analysing data received from these four instruments following valuable information was exposed.

- **Ext 01:** Critical movement - 25/12/2010 to 10/01/2011. Lower portion from the Crack has relatively moved downward. Rate of movement is 7.56 mm per day.
- **Ext 02:** Critical movement- 08/12/2010 to 09/01/2011. Rate of movement is 3.629 mm/day. Lower portion from the major boundary has moved downward.
- **Ext 03:** Critical movement- 25/11/2010 to 09/12/2010. Rate of movement is 17 mm/day. Lower portion from the crack has relatively moved downward.
- **Ext 04:** Critical movement- 27/11/2010 to 27/12/2010. Rate of movement is 1.3 mm/day. Low downward movement compare with the other movements.

3.3. Results of Strain Gauge (SG)

Following are the characteristics of identified slip surfaces using Strain Gauge data.

First 6 months – Mainly two slip surfaces were identified at 13 m and 18 m depth below the location of SG2 (Fig 8). The slip surface at 13 m depth also can be detected at the 11 m depth below the SG1. This has a slow movement with the rain. The effect is varying up to 1m above the slip surface and varies with the rain fall.

Slip surface at 18 m depth below the SG2 has a rapid movement in whole time period which concerned. It has affection area of 1 m above the slip surface and 2 m below the slip surface. That affection area range is changed with the rain fall and continued the same in dry season.

Second 6 months – New two slip surfaces are formed in shallow area with the depth of 4m and 10m below the SG2

3.4. Results of Inclinator

As strain gauge data is not sufficient for correctly defining the slip surfaces, the Inclinator data also has been used. That represents the horizontal movement in sub surface below the location of Inclinator. Those movements are always measured with respect to the end point of the inclinometer bore hole. Those movements are shown in below (Fig 5) and it gives an idea of occurring of a slip surface at 26m depth below the particular location.

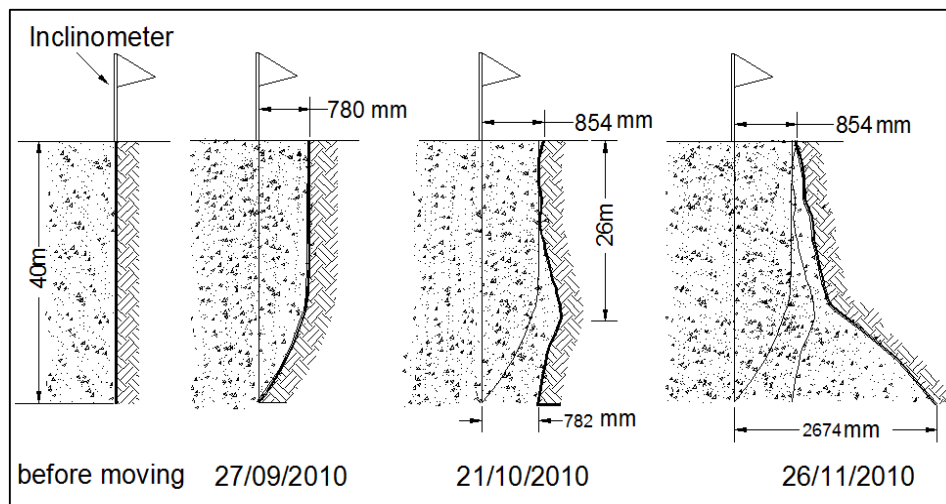


Figure 5 Results of Inclinator

In here the end point of the Inclinator is also have a considerable horizontal movement. It can be happen only if there are slips surfaces occurring bellow the end point of the Inclinator. Then gives an idea about availability of slip surfaces even bellow the 40m depth from the location of Inclinator. All the analysed data about potential slip surfaces in first 6 months which were taken from two strain gauges at the middle area and from 1 Inclinator at top of the slope is summarised as follows (Fig 6, Fig 7).

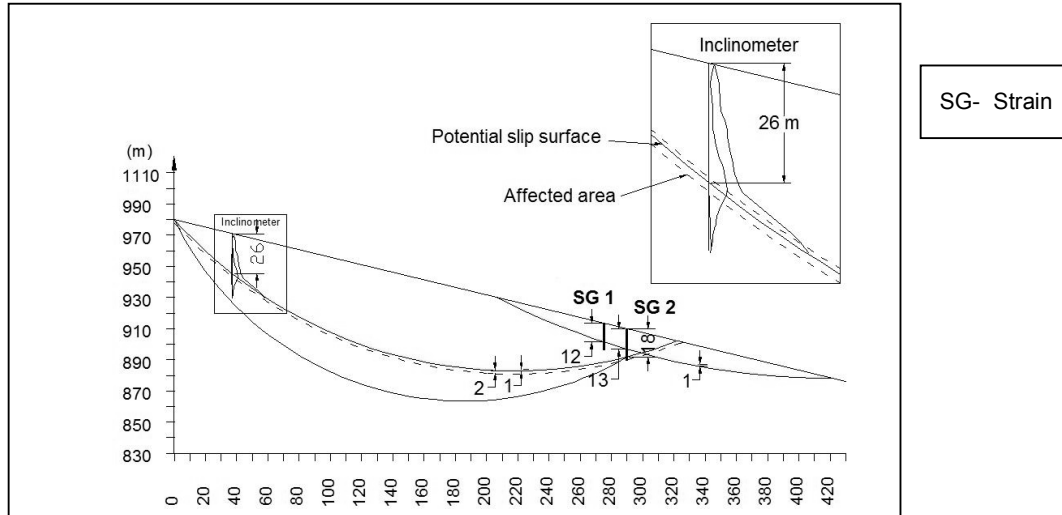


Figure 6 Potential Slip Surfaces at the Mahawewa slope (24/07/2010 to 10/01/2011)

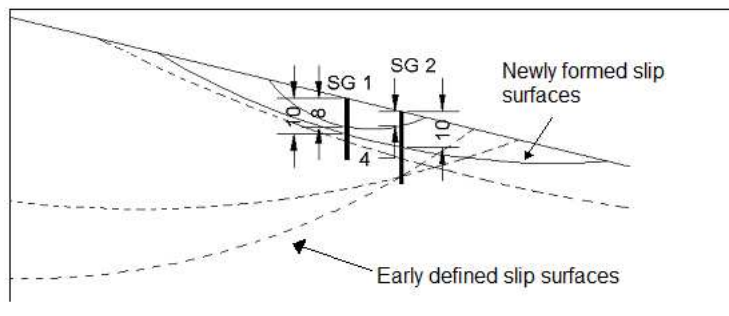


Figure 7 Newly formed Slip Surfaces (10/01/2011 to 14/06/2011)

3.5 Ground Water Level

In dry season (Fig 8)

- Top of the slope – at 2.5 m depth
- Middle area of the slope – 9.82 m depth

In Rainy season (Fig 8)

- Top of the slope – at 1.75 m depth
- Middle area of the slope – 6.64 m depth

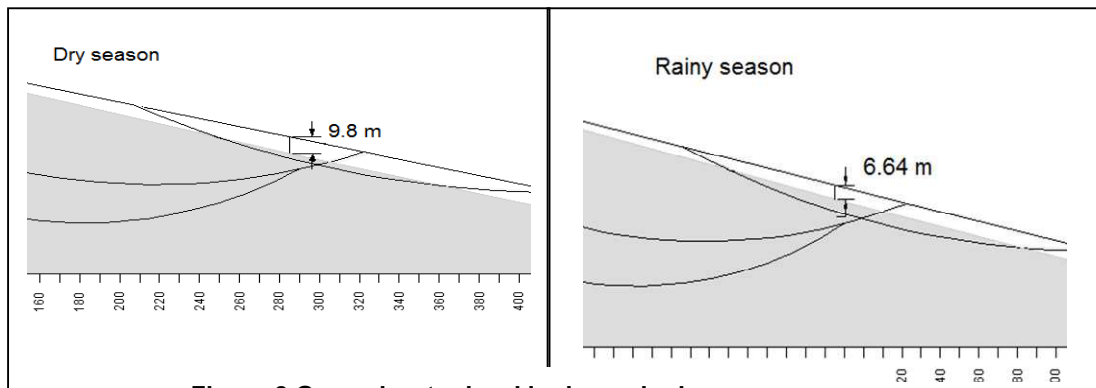


Figure 8 Ground water level in dry and rainy seasons

4. CONCLUSIONS

According to the monitoring data, the type of this Mahawewa landslide is a debris rotational slide, and also rock falling can be seen only at the top of the landslide. Mainly four slip surfaces could be identified and there is a possibility to have another deep slip surface below the 40 m depth of Inclinator station.

However the most critical factor of this landslide is the unfavourable ground water level in slope area. It has been clearly identified that in dry season Piezometer indicates the average ground water level of 2.5 m at the top of the slope and Strain Gauges indicate average ground water level of 9.82 m at the middle area of slope moving axis. In rainy season at the top of the landslide ground water level has been reduced up to 1.5 m level while middle axis of the slope has 6.64 m ground water level. Then it can be concluded that the ground water level is always above the critical slip surfaces even in dry season. So it is better to reduce the water column well below the deepest critical slip surface.

But it is not feasible as well as practicable to establish such a process to reduce the water level completely below the main critical failure surfaces. Then it is suitable to minimize the effect of the water column by reducing the water level down to some optimum extent. Then the weight component of this unfavourable water column is minimized and hence the safety factor can be increased.

Temporally mitigation options also can be used to minimizing the rate of ground displacement of the slip surfaces while introducing proper water proof sealing techniques for the prevention of water entering to the surface cracks. Introducing of well maintaining ditches system is essential. Then can minimize the amount of water accumulated in the abandon reservoir area up to some extent. It also can be performed by designing a surface drainage system of diversion channel system to the top of the landslide to divert the direct water entries from the escarpment which cause to reduce the erosion of the slope.

Not only surface drainage system but also subsurface drainage system can be introduced to remove the accumulated excess water in abounded lake and sliding area. Inserting horizontal or vertical drains are preferred. Furthermore, to increase the feasibility of the project, extracted water can be utilized for the benefit of the people living around Kumbalgamuwa area. For instant surface water can be used for the agricultural activities while using the subsurface water for drinking purposes.

5. ACKNOWLEDGEMENTS

Authors wish to express their sincere gratitude to all academic and non academic staff of the Department of Earth Resources Engineering, University of Moratuwa for their guidance and supports, Dr. Asiri Karunawardane, Director General, National building research Organization (NBRO) and Mr. R.M.S Bandara, Head, Landslide Studies & Services Division (LSSD), NBRO for granting permission to this research as well as for sharing data with this study. Also special thanks should go to Eng. S Fujisawa (JICA - Professional Geo-technical Engineer) for his valuable contributing to the project works.

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